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Extracting Latent Subdimensions of Social Communication: A Cross-measure Factor Analysis RH = Subdimensions of Social Communication

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Abstract

Objective—Social communication deficits associated with autism spectrum disorder (ASD) are commonly represented as one behavioral domain. However, increased precision of measurement of social communication is needed to promote more nuanced phenotyping both within the autism spectrum and across diagnostic boundaries.

Method—A large sample (N=1470) of 4-to-10-year-old children was aggregated from across four data sources, and then randomly split into testing and validation samples. Fifty-seven selected social communication items from three widely used autism symptom measures (ADOS, ADI-R, SRS) were analyzed in the multi-trait/multi-method factor analysis framework. The selected model was then confirmed with the validation sample.

Results—The four substantive-factor model, with three orthogonal method factors, was selected using the testing sample based on fit indices and then confirmed with the validation sample. Two of the factors, “Basic Social Communication Skills” and “Interaction Quality,” were similar to those identified in a previous analysis of the ADOS, Module 3 (Bishop et al., 2016). Two additional factors, “Peer Interaction and Modification of Behavior” and “Social Initiation and Affiliation,” also emerged. Factor scores showed nominal correlations with age and verbal IQ.

Conclusion—Identification of subdimensions could inform the creation of better conceptual models of social communication impairments, including mapping of how the cascading effects of social communication deficits unfold in ASD vs. other disorders. Especially if extended to include both older and younger age cohorts and individuals with more varying developmental levels, these efforts could inform phenotype-based exploration for biological and genetic mechanisms by pinpointing specific mechanisms that contribute to various types of social communication deficits.

Keywords

Autism Diagnostic Observation Scale (ADOS); Autism Diagnostic Interview-Revised (ADI-R); Social Responsiveness Scale (SRS); measurement; phenotyping

Introduction

As the diagnostic criteria for autism spectrum disorder (ASD) have broadened to encompass an even greater diversity of core and associated symptoms,[1] professionals have called for better ways to characterize subtypes within the spectrum.[2] There are multiple reports focused on within-group differences in ASD symptom profiles,[3–5] as well as numerous debates about how best to conceptualize the structure of ASD symptoms (e.g., categorical, dimensional, hybrid).[6–13] Meanwhile, social communication deficits are not specific to ASD, but rather are commonly observed in many other neurodevelopmental disorders (NDDs), including attention deficit hyperactivity disorder, intellectual disability, and language disorders.[14–17] Therefore, increased understanding of different types of social

communication impairments reported or observed in ASD could be helpful not only for identifying subgroups within ASD, but also for differential diagnosis.

Factor analysis (FA) has been commonly employed to identify sub-dimensions of ASD-related symptoms that may be useful for subgrouping or profiling efforts. Several recent analyses of diagnostic tools, such as the Autism Diagnostic Observation Scale (ADOS),[18,19] Autism Diagnostic Interview-Revised (ADI-R),[20] and Social Responsiveness Scale (SRS),[21] have identified two main factors[22–26] (social communication impairments and restricted and repetitive behaviors [RRBs]), informing the move away from three symptom domains in DSM-IV to two domains in DSM-5.[1,25] However, while current conceptualizations of ASD-related impairments *can* be organized into two broad types of symptoms, the extreme heterogeneity in clinical presentations suggests that two domains may be inadequate for describing individual variability in core symptoms. Therefore, as we move forward in our attempts to identify behaviorally and/or etiologically relevant subgroups within ASD, it will be important to increase understanding of subdimensions within these critical, yet broadly defined, behavioral constructs.[27]

Despite longstanding recognition of the variability in social phenotypes (e.g., aloof, passive, active but odd[5]), relatively few studies have specifically sought to dissect social communication impairments in ASD. Early attempts to empirically derive social communication subdomains from diagnostic measures were limited by samples that were too small to validly employ FA or other similar techniques.[28,29] More recently, factor analysis of the ADOS-2 Module 3 algorithm items in 238 school-aged children with and without ASD provided evidence for a “Basic Social Communication Behavior” factor and an “Interaction Quality” factor, which were then replicated in an independent sample of 1,566 children with ASD.[30] Interaction Quality was found to have small correlations with IQ (r= −.21) and male sex (r=.20) in the ASD group, but only with age (r=−.21) in the non-ASD group, while Basic Social Communication was not meaningfully related to any individual child characteristics except ASD diagnostic status. These results suggest that it may be possible to separate social communication into at least two subdimensions: basic social skills needed to execute everyday social behaviors (e.g., eye contact, gestures, facial expression), and interactive and reciprocal social skills that are applied across various social contexts (e.g., conversations, social responses).

FA has also been done with other ASD screening and diagnostic measures. These analyses almost exclusively focused on parent-report measures (e.g., SRS,[31,32] ADI-R,[26] Social Communication Questionnaire[13]), often with items or item parcels mapped onto a priori structures (e.g., DSM 5[26,32] or Research Domain Criteria[13,31]). While most of the FAs included only one measure, one study[33] conducted confirmatory FA with items from both the ADI-R and SRS, which were assigned to four factors ad hoc. The model with four social communication factors showed excellent fit after accounting for shared method variance among items from the same measure. This analysis of more than one measure (and thus a larger and more diverse item set) yielded a greater number of latent constructs (four factors: Nonverbal Communication, Reciprocal Social Interaction, Interpersonal Relatedness, and Social Avoidance[33]) than analyses of the ADI-R or SRS alone.[29,32] It also highlights the potential utility and feasibility of applying FA to combined item sets across measures, while

accounting for methodological factors, in order to extract subdimensions of ASD-related symptoms.

The challenge of identifying subtypes of social communication behaviors is compounded by the developmental nature of these behaviors, since expected behaviors vary across age groups, developmental stages, language levels, and social contexts.[27] As a result, ASD diagnostic instruments are intentionally flexible to be sensitive to social communication deficits characteristic of different developmental levels, and for some instruments, not all individuals are assessed using the same item set. Further, findings from previous studies indicate that, even when item sets are tailored to particular groups of individuals, scores indexing level of social communication impairment continue to be influenced by cognitive abilities and age.[30,34,35] This underscores the need to carefully consider developmental factors when looking for subdimensions of social communication ability, as well as the need for very large samples that can be pre-stratified according to developmental characteristics and item availability.

With the hope of identifying different "types" of social communication impairments, we compiled a large dataset of ADOS, ADI-R and SRS item-level data from verbally fluent, school-aged children with ASD or other NDDs. Recognizing the influences of developmental factors and different assessment modalities, we aimed to take advantage of a large and relatively developmentally homogeneous sample to extract latent subdimensions of social communication deficits across measures. This extended the previous analysis of the ADOS, Module 3 by also including items from two widely used parent-report measures, to see whether similar factors (i.e., Basic Social Communication, Interaction Quality) might also emerge in the cross-measure analysis.

Method

Participants

The current sample was selected from a larger dataset aggregated from four data sources. (For more information on data sources, including inclusion criteria, see Table S1, available online). All participants underwent multi-disciplinary evaluations by experienced clinicians and/or researchers who had established and maintained reliability on the ADOS and ADI-R. Best-estimate clinical diagnoses of ASD or non-ASD were determined based on all available information, including parent-report and direct observation of ASD symptoms, as well as tests of cognitive and adaptive functioning.

Considering item consistency and the impact of developmental factors on social communication, as described above, the current analysis was limited to participants who were between 4 and 10 years of age at the time of the assessment, and who had fluent language abilities as evidenced by their ability to complete Module 3 of the ADOS. Participants who received a score of 2 or 3 on Item A1 (n=11) of Module 3 were excluded, as these scores are given to children who do not produce complex speech during the administration, and therefore Module 3 may not have been appropriate. A total of 1,470 children met the above inclusion criteria and had sufficiently complete data on the items of interest from ADOS, ADI-R, and SRS (see Figure S1, available online, for details about the

sample selection process, available online). In most cases, all three measures were collected within two months of each other. For a small minority of participants (0.9%), the time between tests spanned up to nine months(though all measures were administered as part of the same assessment). We randomly split the sample into training and validation datasets, with 731 in the training dataset for the model generation analyses, and 739 in the validation dataset for confirmatory analyses (Table 1).

Measures

The ADOS-2 is a standardized, semi-structured observational assessment designed to elicit social communication and restricted and repetitive behaviors associated with a diagnosis of ASD. It consists of five modules (Toddler Module, Modules 1-4), one of which is administered based on the child's expressive language and chronological age. In the current analysis, we only included participants who were administered Module 3, designed for children and adolescents with fluent speech.

The ADI-R is an investigator-based parent interview designed to collect information about social communication and restricted and repetitive behaviors associated with a diagnosis of ASD. For each item, the clinician rates whether the abnormality is currently present (i.e., within the past 3 months), and whether the abnormality was present in the past (either during a specific time frame or at any time during the past, depending on the item). For our analysis, we used Current scores from the selected items.

ADOS and ADI-R item scores range from 0 to 3 with specific descriptors for each item. In general, a score of 0 denotes 'abnormality of the type specified is not present' and scores of 2 (or 3) indicate that the 'abnormality is definitely present (and to a degree that interferes with functioning)'. In accordance with scoring and reliability conventions, ADI-R and ADOS scores of 3 were converted to 2s for analysis, while scores of 8 ('Not applicable') and 9 ('Unknown') were converted to 0s.

The SRS is a 65-item parent-report measure designed to index levels of current autism-related symptoms. Each SRS item is rated on a scale from 1='not true' to 4='almost always true'. Some items are reverse coded, such that in all cases, higher scores indicate greater abnormality. In accordance with SRS scoring conventions, responses on the 1 to 4 point response scale were converted to scores of 0-3 for data analysis, with reverse-coding as indicated by the manual. Scores of 3 and 2 were collapsed foritems for which less than 5% of the sample received a score of 3 (A2 "Expressions and sayings don't match"; D34 "Avoids people wanting closeness"; F54 "Reacts to people as objects"; and G60 "Emotionally distant").

Item selection process.

A preliminary set of social communication items from each of the 3 measures was identified based on existing literature and consultation with subject matter experts. Potential items were reviewed by the research team to finalize the item set for FA. From the ADOS-2 Module 3, we selected nine (of ten) algorithm items from the Social Affect domain. *Reporting(A7)* was excluded because it was previously shown to not load with the other

social communication items.[30] We included two other non-algorithm Communication items *(Offers Information(A5)* and *Asks for Information(A6))* which were judged to be related to social communication ability. From the ADI-R, we selected a subset of Current items from the Social and Communication domains that are applicable to verbal children ages 4 to 10 years. Items that have been previously shown to load with RRBs[22]: *Use of other's body to communicate(31), Stereotyped utterances and delayed echolalia(33), Inappropriate questions or statements(36), Pronominal reversal(37), Neologisms/Idiosyncratic language(38)* and *Inappropriate facial expression(58);* and items that were primarily focused on solitary play: *Spontaneous imitation of actions(47)* and *Imaginative play(48)* were excluded. SRS items were selected if they described observable social communication behaviors relevant to interactions with others. We excluded 13 items from the Social Communication/Interaction domain that were judged to be less reflective of core ASD symptoms (e.g., Items *Takes things too literally(10), Has good hygiene(32), Is too tense in social settings(64))* and/or that required the rater to infer the internal state of the individual (e.g., *Has good self-confidence(11)*). Items measuring RRBs were also excluded. However, we retained certain items that are included in the RRBs domain[32] that described behaviors relevant to social communication: *Avoids eye contact (16), Does not join group activities(23), Does not mind being out of step with others(25),* and *Reacts to people as if they are objects(54).*

At last, 57 items were selected from the three measures: ADOS-2 Module 3 (n=11 items), ADI-R Current (n=20 items), and SRS-2 (n=26 items). See Table S2, available online for abbreviated item descriptions corresponding to each item number.

Data preparation and analysis

As stated above, we split the dataset into training and validation subsets. Analyses were based upon a multi-trait/multi-method framework. Initial models were fit using an exploratory-use of confirmatory factor analysis (CFA) process, with the final model evaluated in the validation data. Because the items included in the current analysis originate from three different measures using different formats (i.e., clinician rating from direct observation, clinician rating from parent interview, and parent rating), orthogonal method factors were introduced for each measure to account for the shared method variance.

Second, we explored the optimal number of substantive (i.e., non-method) factors in the training dataset with nested factor models. To approach a saturated model, we started by identifying theoretically-driven item sets to be fixed to zero for different nested models with different numbers of factors (see Table S3, available online). Besides theoretical interpretability, we used a group of commonly-referenced fit indices, including chi-square statistics, Comparative Fit Index (CFI),[36] the Root Mean Square Error of Approximation (RMSEA) and its 90% Confidence Interval (CI), and Standardized Root Mean Square Residual (SRMR). Though some debate exists regarding appropriate cutoffs for non-normal categorical data,[37] in general, nonsignificant chi-square, lower RMSEA and SRMR, and higher CFI should be preferred.

Once the number of factors was selected, we proceeded with iterative model evaluation, allowing cross-loadings of items on multiple factors. Multiple iterations of nested models were fitted, and items were additively and sequentially fixed to zero to achieve an over-

identified CFA model that approached a parsimonious structure. Three criteria were considered when restricting a factor loading: a) the absolute magnitude of the factor loadings; b) the relative magnitude of factor loadings of each item on different substantive factors; and c) the directions of the factor loadings of each item on different substantive factors. When approaching a more stable model, we applied more restrictions to reach a parsimonious model by fixing the parameter estimates for each item to be the same under each method factor. Then, based on modification indices, some of the restricted parameter estimates were freed after an interpretable and parsimonious model was achieved, in order to improve statistical fit.

Next, we applied a CFA using the structure generated by the above step within the validation sample to test whether the factor structure was generalizable. Lastly, a CFA model with a very simple structure was identified with each item loading onto a single substantive factor (plus its method factor), without cross-loadings, for parsimony and clinical interpretability.

The above factor analysis steps were conducted with the Diagonally Weighted Least Squares (DWLS) estimator and robust standard errors using R Package *lavaan* 0.6-5.[38] Within the very simple CFA structure, factor scores were estimated using the *lavPredict* function. Correlations between factor scores and age, and nonverbal and verbal IQ were calculated in the validation sample. Annotated R codes for the FA proportion are included in the Supplement 1, available online.

Results

Five nested models with one through five substantive factors were fit in the training sample to determine the optimal number of substantive factors. The five-factor model did not converge. As indicated in Table 2, $\Delta\chi^2$ were significant for the nested model comparisons when adding more substantive factors, supporting the less restrictive model (i.e., the one with more factors). The models with larger numbers of substantive factors also exhibited better fit indices, indicated by higher CFI, and lower RMSEA and SRMR. Thus, the model with four substantive factors and three method factors was selected.

After multiple iterations with additional restrictions, we arrived at the factor structure shown in Table 3. An item was selected onto the factor on which it had the highest loading, where the absolute value of that loading was >0.3. The final model showed reasonable fit in the training dataset: $\chi^2_{(df=1605)}$ =3739.921 ($p < 0.001$); CFI=0.966 (Robust: 0.958); RMSEA=0.043 (90% CI:0.041 - 0.044); and SRMR=0.063. Table 3 shows the factor loadings of each item on the substantive and method factors. Based on the latent factor structure, the four substantive factors were named as follows: “Interaction Quality” (number of items [ni]=7 with loadings>=0.3), “Peer Interaction and Modification of Behavior” (ni=13), “Social Initiation and Affiliation” (ni=5), and “Basic Social Communication Skills” (ni=24). As shown at the bottom of Table 3, “Basic Social Communication Skills” was highly correlated with “Peer Interaction and Modification of Behavior” (r =0.79). “Interaction Quality” was moderately correlated with all three other factors (0.28, 0.36, 0.38), while “Social Initiation and Affiliation” had very small correlations with the other two factors.

CFA in the validation sample.

The final selected factor structure from the training dataset was tested using CFA in the validation sample, including cross-loadings. The chi-square statistic was significant ($\chi^2_{(df=1473)} = 3705.584$, $p<0.001$), but all other fit indices showed the model to have good to excellent fit (CFI=0.968, Robust=0.961; RMSEA=0.045[90% CI: 0.044 - 0.047]; SRMR=0.062). In the validation dataset, the primary loadings and cross-loadings originally suggested in the training dataset occasionally changed, leaving “Interaction Quality” with eight items, “Peer Interaction and Modification of Behavior” with 13 items, “Social Initiation and Affiliation” with seven items, and “Basic Social Communication Skills” with 21 items (see Table 4). The correlations of the substantive factors were also similar in the validation dataset (see bottom of Table 4), with “Basic Social Communication Skills” and “Peer Interaction and Modification of Behavior” showing the highest correlation (r=0.72), “Interaction Quality” showing moderate correlations with the other three factors (0.29, 0.29, 0.48), and “Social Initiation and Affiliation” showing small correlations with “Peer Interaction and Modification of Behavior” (r=0.13) and “Basic Social Communication Skills” (r=0.09).

CFA model with a very simple structure.

A CFA without cross-loadings was then tested with the validation sample and used to generate factor scores. The CFA results revealed a similar four-substantive-factor structure like the model building results. Although the change in chi-square statistic suggested that model fit was worsened compared to the above CFA model ($\mathbf{\Delta}\chi^2_{(\Delta df=56)} = 413.98$, $p<0.001$), the relative indices showed the model still had good to excellent fit (CFI=0.958, Robust=0.952; RMSEA=0.051[90% CI: 0.049 – 0.053]; SRMR=0.067). The factor scores for “Interaction Quality”, “Peer Interaction and Modification of Behavior” and “Basic Social Communication Skills” were positively correlated with age (r: 0.11, 0.10, 0.13), while only the factor score for “Interaction Quality” negatively correlated with verbal IQ ($r = -0.09$). Though statistically significant, the magnitude of these correlations was nominal.

Discussion

The current analysis contributed to our understanding of subtypes of social communication impairments, by identifying four latent factors from 57 items drawn from three commonly used measures of ASD symptoms. Unlike previous studies that tested ad hoc factor structures,[13,31–33] the current analysis took a data-driven approach to allow factor structures to derive from available data. Identified factors included “Basic Social Communication Skills” and “Interaction Quality” , as previously found in a study that analyzed only the ADOS Module 3 items,[30] as well as “Peer Interaction and Modification of Behavior” and “Social Initiation and Affiliation”. The four-factor structure showed a good fit with both the training and validation samples, with shared method variance directly modeled as a potential confound.

“Basic Social Communication Skills” included items measuring nonverbal communication, joint attention, emotional expression, and emotional recognition. These types of social communication behaviors are typically acquired and mastered during infancy and early

childhood,[39] but are commonly impaired in ASD.[30] Consistent with previous FA studies, nonverbal communication items from the ADI-R and SRS loaded together,[33] as well as ADOS items previously assigned to the "Basic Social Communication" factor.[30]

"Interaction Quality" included mostly ADOS items dealing with quality of conversations, initiations, and responses (with an unfamiliar adult examiner). These items were joined by *Reciprocal Conversation* from the ADI-R (wherein a primary focus is also on conversation with adults) and *Difficulty relating to adults* from the SRS. Thus, "Interaction Quality" measures the *quality* of social interaction, which may involve the *application* of a number of different skills (including Basic Social Communication Skills) required to establish and maintain a successful interaction. Further, in the current analysis, items loading on the Interaction Quality factor all captured interactions with adults (i.e., either in the ADOS context with an unfamiliar adult, or as reported by parents).

The identification of a "Basic Social Communication Skills" and an "Interaction Quality" factor, with substantial item and/or content overlap with the Bishop et al. (2016) study, suggest that these may in fact represent core subdimensions of social communication deficits captured across different autism symptom measures. While ADOS items exclusively loaded on these two factors, the remaining ADI-R and SRS items formed two other factors.

Besides the "Interaction Quality" factor described above, analyses yielded a second factor that concerned quality of interactions with peers. This factor, which we named "Peer Interaction and Modification of Behavior", included predominantly SRS items capturing: (1) the extent to which individuals modify their behaviors to respond and interact with peers appropriately (e.g., take turns, plays appropriately), and (2) the quality of peer interactions (e.g., get teased a lot, difficulty relating to peers). The emergence of two factors related to interaction quality underscores the importance of considering social partners when measuring social communication abilities. Different deficits may impede reciprocal social interactions in different contexts, as different skills are required for successful interactions with adults versus peers. While adults (e.g., caregivers, service providers) often make accommodations to scaffold interactions with children,[40,41] "inappropriate" social behaviors are less likely to be tolerated or accommodated by peers. However, it is unclear whether and how this separation of interaction quality with adults vs. peers would play out in adult samples. It is also important to note that items from "Interaction Quality" dealt largely with conversation. Thus, it will be crucial to examine other samples with lower language and/or cognitive abilities, to see whether these two factors are unique to children with higher verbal abilities.

Lastly, "Social Initiation and Affiliation" included ADI-R items *Imaginative play with peers(49), Imitative social play(61), Interest in children(62), Response to approaches of other children(63), Group play with peers(64)* across both training and validation samples. Two SRS items *Would rather be alone(6)* and *Does not join group activities(23)* were also grouped under this factor in the validation sample. To be rated as a 0 (i.e., indicating absence of abnormality) on any of these items, the individual must independently initiate and/or actively join in activities with others. Rarely considered in conceptualizations of social abilities in typical development,[42] this "motivational" aspect of social communication

behavior stood apart from the other three factors in that it was not significantly correlated with age or IQ within our sample. However, because this sample was purposely selected to reduce heterogeneity in age and language abilities (which is highly correlated with IQ in ASD[43,44]), it was not representative of all individuals with ASD. Therefore, future work will need to examine whether similar factors, and/or relationships between the factors and individual-level phenotypes (age, IQ), emerge in other samples. Studies of measurement invariance across developmental groups will also improve understanding of the latent structures of social communication impairments.

Although the initial model building process required items from all three measures to appear on all substantive factors, as additional restrictions were placed on factor loadings, the representation of multiple measures was reduced. Even after accounting for method factors, there was a tendency for items from one or two measures to dominate each factor. This pattern could be a result of residual method variances, but also could reflect actual differences in the types of impairments captured by the three measures. For example, the ADI-R is focused more on early-emerging, basic social skills, while the SRS probes for "higher-level" skills such as behavior modification within social contexts. Additionally, data collection modalities could influence a measure's ability to reliably gather information about certain social communication deficits. For example, difficulties with peers are better captured by parent report (e.g., ADI-R, and SRS) than direct observation in the clinic (i.e., ADOS). At the same time, these measures were also developed with these constraints in mind (e.g., the ADOS cannot realistically measure anything having to do with peers). Thus, while the identified factors may reveal something about the construct of social communication, they are also a reflection of the specific measures from which they were derived.

The set of social communication behaviors included in the current FA were drawn from ASD *symptom* measures. As a result, the latent constructs extracted here rely heavily on historical conceptualizations of social communication as related to ASD. Moreover, items were selected based on previous literature and expert knowledge. While this process was informed by subject matter experts and skilled clinicians, limiting the analyses to a subset of items introduces potential bias in the factor results. There are undoubtedly other important facets of social communication behavior not captured by any of these measures and therefore not available for the current analysis. Nevertheless, the attempt to consider social communication as measured by three different instruments promotes a more nuanced understanding of different types of social communication impairments.

This sample was comprised primarily of males with ASD, either clinically referred for evaluation of ASD, or specifically recruited for ASD-related research studies, and limited in age group and developmental/language level to school-aged children with fluent language. Thus, social communication impairments are expected to be highly prevalent in the current sample and our findings are driven by social communication deficits related to ASD. Previous analyses of ASD symptom measures like the SRS indicate that individuals with and without ASD, and individuals from clinical and nonclinical samples, not only vary in the distribution of overall severity scores[45], but also in their manifestations of social communication impairments (i.e., the factor structure is not invariant across different

groups).[32] Therefore, while our findings may offer some insights into how social communication skills develop typically or in non-ASD populations, much more work in nonclinical and non-ASD samples, and using measures not specifically designed for ASD populations, are needed to understand the full range of latent constructs underlying social communication impairment or ability.

Although restricted by the availability of data (i.e., measures that are limited in capturing the full range of social communication abilities across developmental groups[46]), this cross-measure FA is a step forward in the exploration of multiple subdimensions within the broader social communication domain. In addition to previously identified "Basic Social Communication Skills" and "Interaction Quality" factors, analyses indicated two other latent constructs (i.e., "Peer Interaction and Modification of Behavior" and "Social Initiation and Affiliation"). These findings provide insights into both the structure of social communication impairments, as currently measured, as well as what may need to be considered in the development of a more comprehensive social communication measure.

Because deficits in social communication are both core to a diagnosis of ASD, and commonly observed in other NDDs, increased precision of measurement of social communication will promote more nuanced phenotyping both within the autism spectrum and guide further explorations across diagnostic boundaries. Further, these efforts, especially if extended to include both older and younger age corhorts and individuals with more varying developmental levels, could inform phenotype-based exploration for biological and genetic mechanisms for ASD and even other NDDs by pinpointing specific mechanisms that contribute to different types of social communication deficits. Identification of subtypes could also inform the creation of better conceptual models of social communication impairments, including mapping of how the cascading effects of social communication deficits actually unfold in ASD vs. other disorders, or typical development.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Table 1:

Demographic Information of Included Cases in Training and Validation Samples

		Training (n=731)		Validation (n=739)	
		N, Mean (SD)	Range	N, Mean (SD)	Range
	Age in Months	731, 93.31 (20.76)	49-131	739, 94.01 (20.52)	49-131
	FSIQ	711, 96.24 (17.47)	47-165	720, 97.03 (17.52)	41-159
	VIQ	730, 96.02 (17.82)	38-161	738, 96.549 (17.95)	40-166
	NVIQ	731, 98.26 (17.81)	44-159	739, 99.18 (17.68)	41-158
		N	%	N	%
NVIQ	>=80	630	85.60	652	87.28
	>=70	696	94.57	713	95.45
Sex	Male	621	84.95	626	84.71
	Female	110	15.05	113	15.29
Diagnosis	ASD	663	90.70	668	90.39
	Non-ASD	68	9.30	71	9.61
Race	White/Caucasian	554	75.79	579	78.35
	African American	26	3.56	16	2.17
	Asian/Pacific Islander	18	2.46	16	2.17
	American Indian or Alaskan native	3	0.41	2	0.27
	Other/Multiracial	69	9.43	62	8.39
	Missing	61	8.34	64	8.66
Ethnicity	Non-Hispanic	606	82.90	624	84.43
	Hispanic	61	8.34	49	6.63
	Missing	64	8.76	66	8.93
Number of cases from Each Site	Simons Simplex Collection	521	71.27%	522	70.64%
	Center for Autism and Developing Brain Databank	155	21.20%	158	21.38%
	McMaster University Pathways Study	55	7.52%	57	7.71%
	NIMH Databank[a]	0		2	0.27%

Note: There were no significant differences between the two datasets. All data were accessed upon request through publicly available datasets or registries maintained by research institutes. FSIQ = full scale IQ; NVIQ = nonverbal IQ; VIQ = verbal IQ

[a]Data from the Pediatrics and Developmental Neuroscience Branch, National Institute of Mental Health

Table 2.

Fit Indices and Comparisons of Nested Exploratory Factor Models

Substantive Factor #	χ^2 (Robust)	df	CFI (Robust)	RMSEA (90% CI)	SRMR	$\Delta\chi^2$
1	5010.319 (6989.002)	1617	0.946 (0.914)	0.054 (0.052, 0.055)	0.074	
2	3348.579 (5050.190)	1595	0.971 (0.944)	0.040 (0.038,0.041)	0.060	749.45 p <.001
3	2295.433 (3722.416)	1506	0.987 (0.978)	0.027 (0.025, 0.029)	0.051	544.6 p <.001
4	1634.113 (2791.119)	1452	0.997 (0.987)	0.013 (0.009, 0.016)	0.043	454.48 p <.001
5-factor nested model did not converge						

Note: CFI = comparative fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual.

Table 3.

Item Factor Loadings on Substantive and Method Factors During Model Generation in the Training Sample

	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
ADOS: Conversation	**0.61 (0.53, 0.69)**[b]	−0.11 (−0.22, 0)	0[c]	0	***0.58***	*0*	*0*
ADOS: Amount of Reciprocal Social Communication	**0.59 (0.50, 0.68)**	0	0.03 (−0.06, 0.11)	−0.14 (−0.23, −0.05)	***0.58***	*0*	*0*
ADOS: Quality of Social Response	**0.52 (0.44, 0.60)**	0.04 (−0.11, 0.19)	0	−0.03 (−0.16, 0.11)	***0.58***	*0*	*0*
ADIR: Reciprocal Conversation	**0.46 (0.38, 0.54)**	0.24 (0.15, 0.32)	0	0	*0*	***0.40***	*0*
ADOS: Overall Quality of Rapport	**0.41 (0.34, 0.48)**	−0.05 (−0.13, 0.02)	0	0	***0.58***	*0*	*0*
ADOS: Quality of Social Overtures	**0.34 (0.27, 0.41)**	0.23 (0.09, 0.37)	0	−0.08 (−0.20, 0.05)	***0.58***	*0*	*0*
SRS_D36: Has difficulty relating to adult	**0.32 (0.22, 0.41)**	0.31 (0.23, 0.39)	0.03 (−0.05, 0.10)	0	*0*	*0*	***0.24***
ADOS: Offers Information	**0.29**[d] **(0.22, 0.35)**	0	0.13 (0.05, 0.20)	0	***0.58***	*0*	*0*
ADOS: Asks for Information	**0.15 (0.09, 0.20)**	0	0.09 (0.02, 0.15)	0	***0.58***	*0*	*0*
SRS_D37: Has difficulty relating to peers	0	**0.79 (0.75, 0.84)**	0.24 (0.18, 0.30)	0	*0*	*0*	***0.24***
SRS_D33: Is socially awkward, even when he or she is trying to be polite.	0	**0.73 (0.70, 0.76)**	0	0	*0*	*0*	***0.24***

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	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
SRS_B18: Has difficulty making friends, even when trying his or her best.	0	**0.72 (0.69, 0.74)**	0	0	*0*	*0*	***0.24***
SRS_B13:Is awkward in turn taking with peers	−0.03 (−0.12, 0.06)	**0.65 (0.59, 0.70)**	0.04 (−0.03, 0.12)	0	*0*	*0*	***0.24***
SRS_C22: Plays appropriately with children his or her age	0	**0.63 (0.59, 0.67)**	0.22 (0.17, 0.28)	0	*0*	*0*	***0.24***
SRS_D38: Responds appropriately to mood changes in others	0	**0.55 (0.52, 0.58)**	0	0	*0*	*0*	***0.24***
SRS_D35: Trouble keeping up with a normal conversation	0.26 (0.19, 0.33)	**0.52 (0.46, 0.58)**	0	0	*0*	*0*	***0.24***
SRS_A5: doesn't know when others are trying to take advantage of him/her	0	**0.49 (0.45, 0.52)**	0	0	*0*	*0*	***0.24***
SRS_F52: Knows when being too loud	−0.13 (−0.21, −0.05)	**0.45 (0.39, 0.51)**	0	0	*0*	*0*	***0.24***
SRS_F57: Gets teased a lot	0	**0.41 (0.38, 0.45)**	0	0	*0*	*0*	***0.24***
SRS_F55: Knows when he or she is too close to someone or is invading someone's space.	0	**0.40 (0.36, 0.43)**	0	0	*0*	*0*	***0.24***
ADIR: Social Disinhibition	0	**0.37 (0.33, 0.40)**	0	0	*0*	***0.40***	*0*
SRS_C25: Doesn't seem to mind being out of step with others.	0	**0.33 (0.28, 0.38)**	0.25 (0.19, 0.30)	0	*0*	*0*	*0.24*
ADIR: Appropriateness of Social Responses	0.25 (0.17, 0.33)	**0.29 (0.22, 0.36)**	0	0	*0*	***0.40***	*0*
ADIR: Response to Approaches of Other Children	0	0.33 (0.22, 0.44)	**0.72 (0.66, 0.77)**	0	*0*	***0.40***	*0*

	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
ADIR: Group Play with Peers	0	0.29 (0.18, 0.39)	**0.68 (0.62, 0.73)**	0	*0*	***0.40***	*0*
ADIR: Interest in Children	0	0	**0.63 (0.57, 0.69)**	0.21 (0.12, 0.31)	*0*	***0.40***	*0*
ADIR: Imaginative Play with Peers	0	0.26 (0.18, 0.35)	**0.51 (0.46, 0.57)**	0	*0*	***0.40***	*0*
ADIR: Imitative Social Play	0	0	**0.45 (0.40, 0.50)**	0.33 (0.26, 0.40)	*0*	***0.40***	*0*
ADIR: Offering Comfort	0	−0.38 (−0.52, −0.24)	0.05 (−0.02, 0.11)	**0.86 (0.73, 0.99)**	*0*	***0.40***	*0*
SRS_G60: Is emotionally distant, doesn't show his or her feelings.	0	−0.26 (−0.39, 0.12)	0.11 (0.05, 0.18)	**0.81 (0.67, 0.94)**	*0*	*0*	***0.24***
SRS_C26: Offers comfort to others when they are sad.	0	−0.28 (−0.40, −0.16)	0.13 (0.07, 0.19)	**0.77 (0.65, 0.89)**	*0*	*0*	***0.24***
ADIR: Range of Facial Expressions Used to Communicate	0	−0.12 (−0.25, 0)	0	**0.65 (0.53, 0.77)**	*0*	***0.40***	*0*
SRS_A2: Expressions on his or her face don't match what he or she is saying	0	−0.07 (−0.20, 0.05)	0	**0.64 (0.52, 0.75)**	*0*	*0*	***0.24***
SRS_F54: Seems to react to people as if they are objects	0	0	0.03 (−0.04, 0.09)	**0.58 (0.54, 0.61)**	*0*	*0*	***0.24***
SRS_D34: Avoids people who want to be emotionally close to him or her.	0	0	0.21 (0.15, 0.28)	**0.58 (0.53, 0.62)**	*0*	*0*	***0.24***
ADIR: Social Smiling	0	0	0.08 (0.02, 0.14)	**0.56 (0.45, 0.67)**	*0*	***0.40***	*0*
SRS_B16: Avoids eye contact or has unusual eye contact	0	0	0	**0.52 (0.49, 0.55)**	*0*	*0*	*0.24*

	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
ADIR: Seeking to Share Enjoyment with Others	0	−0.07 (−0.20, 0.06)	0.04 (−0.02, 0.11)	**0.51 (0.38, 0.63)**	*0*	***0.40***	*0*
ADIR: Conventional/Instrumental Gestures	0	0	0	**0.50 (0.47, 0.54)**	*0*	***0.40***	*0*
SRS_C23: Does not join group activities unless told to do so.	0	0	0.48 (0.43, 0.54)	**0.49 (0.41, 0.56)**	*0*	*0*	***0.24***
SRS_A12: Is able to communicate his or her feelings to others.	0.11 (0.04, 0.18)	0	0	**0.47 (0.42, 0.53)**	*0*	*0*	***0.24***
SRS_C27: Avoids starting social interactions peers and adults.	0	0	0.44 (0.38, 0.50)	**0.47 (0.40, 0.54)**	*0*	*0*	***0.24***
ADIR: Showing and Directing Attention	0	0	0.13 (0.06, 0.19)	**0.47 (0.43, 0.51)**	*0*	***0.40***	*0*
ADIR: Pointing	0	0	−0.11 (−0.17, −0.04)	**0.44 (0.40, 0.47)**	*0*	***0.40***	*0*
SRS_A6: Would rather be alone than with others	0	0	0.36 (0.31, 0.42)	**0.43 (0.37, 0.49)**	*0*	*0*	***0.24***
ADIR: Quality of Social Overtures	0	0	−0.04 (−0.10, 0.03)	**0.42 (0.37, 0.46)**	*0*	***0.40***	*0*
SRS_B15: Is able to understand the meaning of other people's tone of voice and facial expressions	0	0.07 (−0.04, 0.18)	0	**0.39 (0.29, 0.50)**	*0*	*0*	***0.24***
SRS_E45: Focuses his or her attention to where others are looking or listening	0	0.05 (−0.06, 0.16)	0.05 (−0.01, 0.10)	**0.39 (0.28, 0.50)**	*0*	*0*	***0.24***
ADOS: Unusual Eye Contact	0	0	0	**0.34 (0.30, 0.38)**	***0.58***	*0*	*0*
ADIR: offering to share	0	0.01 (−0.11, 0.13)	0.20 (0.14, 0.26)	**0.33 (0.22, 0.45)**	*0*	***0.40***	*0*

	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
ADIR: Social Verbalization/Chat	0.30 (0.21, 0.38)	0	−0.10 (−0.17, −0.02)	**0.32 (0.56, 0.39)**	*0*	***0.40***	*0*
SRS_A7: Is aware of what others are thinking or feeling	0	0.24 (0.14, 0.35)	0	**0.32 (0.21, 0.42)**	*0*	*0*	***0.24***
ADIR: Head Shaking	0	0	0	**0.29 (0.26, 0.33)**	*0*	***0.40***	*0*
ADIR: Nodding	0	0	0	**0.29 (0.26, 0.33)**	*0*	***0.40***	*0*
ADOS: Facial Expressions Directed to Others	0	0	0	**0.22 (0.19, 0.25)**	***0.58***	*0*	*0*
ADOS: Shared Enjoyment in Interaction	0	0	0.11 (0.05, 0.17)	**0.20 (0.16, 0.23)**	***0.58***	*0*	*0*
ADOS: Descriptive, Conventional, Instrumental, or Informational Gestures	0	0	0	**0.17 (0.14, 0.20)**	***0.58***	*0*	*0*
Correlations between substantive factors							
Interaction Quality	1						
Peer Interaction and Modification of Behavior	0.38	1					
Social Initiation and Affiliation	0.28	−0.15	1				
Basic Social Communication Skills	0.36	0.79	−0.12	1			

Note: Boldface type indicates item loadings that are the largest across factors and larger than 0.3ADOS = Autism Diagnostic Observation Scale; ADI-R = Autism Diagnostic Interview-Revised; SRS = Social Responsiveness Scale.

[a]The method factor variances are: ADOS: 0.51, ADI-R: 0.43, SRS: 0.22.

[b]95% CI for parameter estimates were included in the parentheses.

[c]Item loadings of 0 indicate that the items were fixed under the specific factors.

[d]Item loadings below 0.3 but still the largest loading across factors are bolded as they were considered as under that specific factors.

Table 4.

Item Factor loadings on Substantive and Method Factors with Validation Dataset

	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
ADOS: Conversation	**0.52 (0.45, 0.60)**[b]	−0.07 (−0.15, 0.02)	0[c]	0	***0.62***	*0*	*0*
ADOS: Amount of Reciprocal Social Communication	**0.54 (0.44, 0.65)**	0	0.02 (−0.06, 0.10)	−0.06 (−0.15, 0.03)	***0.62***	*0*	*0*
ADOS: Quality of Social Response	**0.36 (0.28, 0.45)**	0.09 (−0.02, 0.20)	0	−0.03 (−0.15, 0.09)	***0.62***	*0*	*0*
ADIR: Reciprocal Conversation	**0.57 (0.50, 0.65)**	0.31 (0.22, 0.39)	0	0	*0*	***0.35***	*0*
ADOS: Overall Quality of Rapport	**0.28**[d] **(0.21, 0.35)**	0.02 (−0.04, 0.09)	0	0	***0.62***	*0*	*0*
ADOS: Quality of Social Overtures	**0.33 (0.24, 0.41)**	0.23 (0.12, 034)	0	−0.09 (−0.21, 0.03)	***0.62***	*0*	*0*
SRS_D36: Has difficulty relating to adult	**0.38 (0.30, 0.46)**	0.27 (0.20, 0.34)	0.06 (−0.01, 0.13)	0	*0*	*0*	***0.29***
ADOS: Offers Information	**0.34 (0.28, 0.41)**	0	0.06 (−0.02, 0.14)	0	***0.62***	*0*	*0*
ADOS: Asks for Information	**0.2 (0.14, 0.26)**	0	0.01 (−0.06, 0.08)	0	***0.62***	*0*	*0*
ADIR: Appropriateness of Social Responses	**0.41 (0.34, 0.49)**	0.26 (0.19, 0.34)	0	0	*0*	***0.35***	*0*
SRS_D37: Has difficulty relating to peers	0	**0.76 (0.72, 0.79)**	0.15 (0.09, 0.21)	0	*0*	*0*	***0.29***

	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
SRS_D33: Is socially awkward, even when he or she is trying to be polite.	0	**0.7 (0.67, 0.73)**	0	0	*0*	*0*	***0.29***
SRS_B18: Has difficulty making friends, even when trying his or her best.	0	**0.68 (0.65, 0.71)**	0	0	*0*	*0*	***0.29***
SRS_B13:Is awkward in turn taking with peers	0.08 (0, 0.15)	**0.55 (0.50, 0.60)**	0.02 (−0.04, 0.09)	0	*0*	*0*	***0.29***
SRS_C22: Plays appropriately with children his or her age	0	**0.56 (0.52, 0.60)**	0.17 (0.11, 0.23)	0	*0*	*0*	***0.29***
SRS_D38: Responds appropriately to mood changes in others	0	**0.57 (0.54, 0.60)**	0	0	*0*	*0*	***0.29***
SRS_D35: Trouble keeping up with a normal conversation	0.33 (0.27, 0.40)	**0.38 (0.32, 0.45)**	0	0	*0*	*0*	***0.29***
SRS_A5: doesn’t know when others are trying to take advantage of him/her	0	**0.36 (0.32, 0.39)**	0	0	*0*	*0*	***0.29***
SRS_F52: Knows when being too loud	0.03 (−0.05, 0.10)	**0.4 (0.34, 0.45)**	0	0	*0*	*0*	***0.29***
SRS_F57: Gets teased a lot	0	**0.37 (0.34, 0.45)**	0	0	*0*	*0*	***0.29***
SRS_F55: Knows when he or she is too close to someone or is invading someone’s space.	0	**0.3 (0.26, 0.33)**	0	0	*0*	*0*	***0.29***
ADIR: Social Disinhibition	0	**0.35 (0.31, 0.38)**	0	0	*0*	***0.35***	*0*
SRS_C25: Doesn’t seem to mind being out of step with others.	0	**0.31 (0.26, 0.35)**	0.18 (0.12, 0.24)	0	*0*	*0*	***0.29***
ADIR: Response to Approaches of Other Children	0	0.21 (0.12, 0.31)	**0.67 (0.61, 0.73)**	0	*0*	***0.35***	*0*

	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
ADIR: Group Play with Peers	0	0.11 (0.02, 0.20)	**0.65 (0.59, 0.70)**	0	*0*	***0.35***	*0*
ADIR: Interest in Children	0	0	**0.63 (0.57, 0.70)**	0.15 (0.07, 0.24)	*0*	***0.35***	*0*
ADIR: Imaginative Play with Peers	0	0.17 (0.10, 0.25)	**0.48 (0.43, 0.54)**	0	*0*	***0.35***	*0*
ADIR: Imitative Social Play	0	0	**0.54 (0.48, 0.59)**	0.23 (0.16, 0.30)	*0*	***0.35***	*0*
SRS_C23: Does not join group activities unless told to do so.	0	0	**0.5 (0.45, 0.56)**	0.42 (0.35, 0.49)	*0*	*0*	***0.29***
SRS_A6: Would rather be alone than with others	0	0	**0.4 (0.35, 0.46)**	0.39 (0.33, 0.45)	*0*	*0*	***0.29***
ADIR: Offering Comfort	0	−0.07 (−0.17, 0.04)	0.02 (−0.05, 0.09)	**0.67 (0.58, 0.76)**	*0*	***0.35***	*0*
SRS_G60: Is emotionally distant, doesn't show his or her feelings.	0	−0.26 (−0.38, −0.14)	0.08 (0.01, 0.15)	**0.77 (0.66, 0.88)**	*0*	*0*	***0.29***
SRS_C26: Offers comfort to others when they are sad.	0	−0.16 (−0.26, −0.06)	0.09 (0.03, 0.16)	**0.66 (0.50, 0.69)**	*0*	*0*	***0.29***
ADIR: Range of Facial Expressions Used to Communicate	0	0.05 (−0.05, 0.15)	0	**0.52 (0.43, 0.61)**	*0*	***0.35***	*0*
SRS_A2: Expressions on his or her face don't match what he or she is saying	0	−0.02 (−0.12, 0.08)	0	**0.6 (0.50, 0.69)**	*0*	*0*	***0.29***
SRS_F54: Seems to react to people as if they are objects	0	0	0.09 (0.02, 0.16)	**0.56 (0.52, 0.61)**	*0*	*0*	***0.29***
SRS_D34: Avoids people who want to be emotionally close to him or her.	0	0	0.23 (0.17, 0.30)	**0.52 (0.47, 0.57)**	*0*	*0*	***0.29***

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	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
ADIR: Social Smiling	0	−0.18 (−0.28, −0.07)	0.18 (0.12, 0.24)	**0.67 (0.57, 0.76)**	*0*	***0.35***	*0*
SRS_B16: Avoids eye contact or has unusual eye contact	0	0	0	**0.56 (0.53, 0.59)**	*0*	*0*	***0.29***
ADIR: Seeking to Share Enjoyment with Others	0	−0.23 (−0.35, −0.11)	0.15 (0.08, 0.22)	**0.69 (0.58, 0.80)**	*0*	***0.35***	*0*
ADIR: Conventional/Instrumental Gestures	0	0	0	**0.52 (0.49, 0.55)**	*0*	***0.35***	*0*
SRS_A12: Is able to communicate his or her feelings to others.	−0.02 (−0.10, 0.07)	0	0	**0.5 (0.44, 0.56)**	*0*	*0*	***0.29***
SRS_C27: Avoids starting social interactions peers and adults.	0	0	0.38 (0.33, 0.44)	**0.43 (0.37, 0.49)**	*0*	*0*	***0.29***
ADIR: Showing and Directing Attention	0	0	0.09 (0.02, 0.15)	**0.49 (0.45, 0.53)**	*0*	***0.35***	*0*
ADIR: Pointing	0	0	−0.03 (−0.09, 0.04)	**0.44 (0.40, 0.47)**	*0*	***0.35***	*0*
ADIR: Quality of Social Overtures	0	0	0.01 (−0.06, 0.07)	**0.58 (0.55, 0.62)**	*0*	***0.35***	*0*
SRS_B15: Is able to understand the meaning of other people's tone of voice and facial expressions	0	0.14 (0.05, 0.23)	0	**0.25 (0.17, 0.33)**	*0*	*0*	***0.29***
SRS_E45: Focuses his or her attention to where others are looking or listening	0	0.18 (0.09, 0.27)	0.08 (0.02, 0.14)	**0.24 (0.16, 0.32)**	*0*	*0*	***0.29***
SRS_A7: Is aware of what others are thinking or feeling	0	0.12 (0.03, 0.21)	0	**0.4 (0.32, 0.48)**	*0*	*0*	***0.29***
ADOS: Unusual Eye Contact	0	0	0	**0.29 (0.25, 0.32)**	***0.62***	*0*	*0*

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	Substantive Factors				*Method Factors*[a]		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	***ADOS***	***ADI***	***SRS***
Item Identifier	**Interaction Quality**	**Peer Interaction and Modification of Behavior**	**Social Initiation and Affiliation**	**Basic Social Communication Skills**			
ADIR: offering to share	0	0.09 (0, 0.19)	0.22 (0.16, 0.29)	**0.38 (0.29, 0.47)**	*0*	***0.35***	*0*
ADIR: Social Verbalization/Chat	0.29 (0.20, 0.38)	0	0.1 (0.03, 0.17)	**0.35 (0.28, 0.41)**	*0*	***0.35***	*0*
ADIR: Head Shaking	0	0	0	**0.29 (0.26, 0.33)**	*0*	***0.35***	*0*
ADIR: Nodding	0	0	0	**0.31 (0.27, 0.34)**	*0*	***0.35***	*0*
ADOS: Facial Expressions Directed to Others	0	0	0	**0.3 (0.27, 0.33)**	***0.62***	*0*	*0*
ADOS: Shared Enjoyment in Interaction	0	0	0.19 (0.13, 0.25)	**0.27 (0.22, 0.31)**	***0.62***	*0*	*0*
ADOS: Descriptive, Conventional, Instrumental, or Informational Gestures	0	0	0	**0.14 (0.10, 0.17)**	***0.62***	*0*	*0*
Correlations between substantive factors							
Interaction Quality	1						
Peer Interaction and Modification of Behavior	0.29	1					
Social Initiation and Affiliation	0.29	0.13	1				
Basic Social Communication Skills	0.48	0.71	0.09	1			

Note: Boldface type indicates item loadings that are the largest across factors and larger than 0.3. ADOS = Autism Diagnostic Observation Scale; ADI-R = Autism Diagnostic Interview-Revised; SRS = Social Responsiveness Scale.

[a]The method factor variances are: ADOS: 0.38, ADI-R: 0.12, SRS: 0.08.

[b]95% CI for parameter estimates were included in the parentheses.

[c]Item loadings of 0 indicate that the items were fixed under the specific factors.

[d]Item loadings below 0.3 but still the largest loading across factors are bolded as they were considered as under that specific factors.